5th Asia-Pacific Conference on Plasma Physics, 26 Sept-1Oct, 2021, Remote e-conference

The Fluid-Kinetic Transition of Alfvén Wave Turbulence

Trevor A. Bowen[1], Alfred Mallet[1], Christopher H. K. Chen[2], Stuart D. Bale[1], Lloyd Woodham[3], Die Duan[4], Jiansen He[4], Jonathan Squire[5], Romain Meyrand[5]

[1] Space Sciences Laboratory, UC Berkeley, [2] School of Physics and Astronomy, Queen Mary University, [3] The Blackett Laboratory, Imperial [4] College School of Earth and Space Sciences, Peking University,[5] Department of Physics, University of Otago

tbowen@berkeley.edu

Magnetized plasma environments are often subject to significant nonlinear turbulent interactions that effectively cascade energy from large to small scales. At scales much larger than ion-kinetic lengths, magnetohydrodynamic (MHD) approximations are commonly used in understanding nonlinear turbulent energy transfer. Historically, the solar wind and terrestrial space environments have provided much of the observational context for understanding turbulence in magnetized plasms. Observations of MHD-range turbulence in the solar wind reveal spectra similar to neutral-hydrodynamic turbulence with an approximate $k^{-5/3}$ spectral scaling. Theoretical and observational considerations suggest that the cascade of energy is driven by nonlinear interactions between Alfvén waves.

Recent observations from the Parker Solar Probe (PSP) mission have enabled studies of MHD range turbulence in the inner heliosphere, which is often characterized by high-cross helicity (i.e. approximately Alfvénic) states. The collisionless dissipation of this turbulence is likely a significant mechanism contributing to heating and acceleration of the extended solar atmosphere. However, the specific processes responsible for dissipating magnetized turbulence in collisionless plasmas is poorly understood.

At ion-kinetic scales (e.g. ion gyro and inertial scales) it is often observed that the spectrum steepens to an approximate $k^{-2.8}$ scaling. The steepening of the spectrum is largely consistent with the breakdown of MHD approximations and a shift of nondispersive Alfvén wave turbulence to dispersive kinetic Alfvén wave (KAW) turbulence. The KAW dispersion can explain spectral steepening without invoking heating or dissipative effects.

Around ion-kinetic scales , i.e., at the transition range between MHD $k^{-5/3}$ spectrum and sub-ion-kinetic $k^{-2.8}$ spectrum, significantly steeper spectral scalings of approximately k^{-4} have been observed in the solar wind at 1 AU. Recent observations of the inner-heliosphere from the PSP mission have revealed enhanced steepening associated with the transition range, suggesting that the steepening is likely an important signature of nonlinear dynamics occurring in the inner heliosphere where plasma heating and acceleration are pronounced.

Here, we discuss the observational signatures of the transition between Alfvén wave and KAW turbulence in PSP observations: spectral shape, indices, anisotropy, helicity, and intermittent properties. While the specific cause of the transition range steepening has yet to be identified, we additionally discuss several mechanisms which may generate the observed signatures, including dissipation, co-propagating KAW interactions, well as anomalous nonlinear spectral transfer. We additionally compare the observations to the results of Finite-Larmor-Radius MHD models that resolve steepening as the result of a helicity/energy flux barrier in highly imbalanced turbulence.

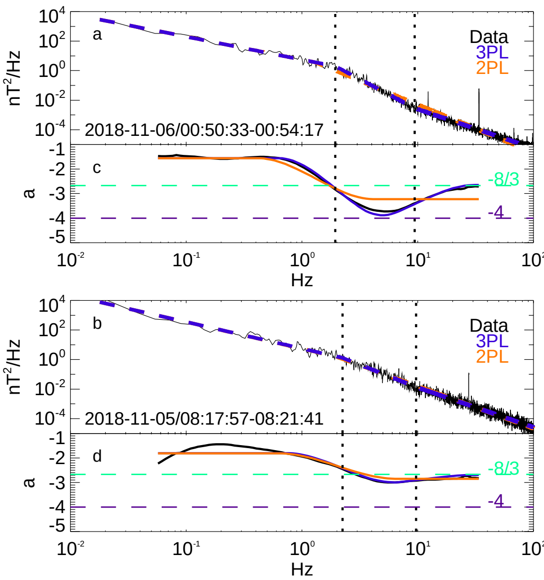

Figure: Two intervals of PSP/FIELDS merged magnetic field spectra [1-2].. Transition range steepening to k^{-4} spectral index observed in interval corresponding to the top panel.

References

[1] Bowen et al. JGR, 125, e2020JA027813, (2020)
[2] Bowen et al. PRL, 125, 025102, (2020)
[3] Duan et al. ApJL, 915, L8, (2021)
[4] Meyrand et al. JPP, 87(3), 535870301, (2021)
[5] Woodham et al. 2021 (in prep)